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Book Review

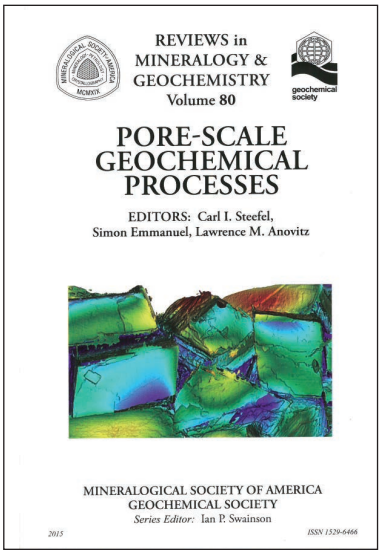
Book Review: Pore-Scale Geochemical Processes, RIMG Volume 80. Edited by Carl I. Steefel, Simon Emmanuel, and Lawrence M. Anovitz. (2015) Reviews in Mineralogy and Geochemistry, i-xiv + 491 p. Open Access, ISBN 978-0-939950-96-6.

Efforts to understand geochemical processes in Earth's materials have repeatedly revealed their complexity and the need to understand mechanisms at finer and finer spatial scales. This has driven us to probe deeper than the "continuum scale," into fractures, pores, grains, coatings, nanopores, and molecules themselves. Recent rapid advances in imaging and computational power have enabled molecules in small spaces to whisper their secrets to us.

In this volume, editors Carl Steefel, Simon Emmanuel, and Larry Anovitz have collected in one place the current state of knowledge on pore-scale geochemical processes. The chapters are written by leading experts on an array of topics ranging from materials characterization, to mineralogy and surface chemistry, to reaction thermodynamics and kinetics, and to reactive transport modeling. Quoting Steefel, Beckingham, and Landrot, "New capabilities … offer the potential for a paradigm shift in the Earth Sciences that will allow us to understand and ultimately quantify such enigmas as the apparent discrepancy between laboratory and field rates … and the impact of geochemical reactions on the transport properties of subsurface materials."

It is clear from the chapters collected in this volume that to have a robust predictive capability of geochemical and physical processes will require a pore-scale view. Therefore, one of the most important chapters, by Anovitz and Cole, comprehensively describes the latest techniques for microscopic characterization of materials in Earth sciences, offering scientists an unprecedented ability to study geochemical processes at the pore scale. This chapter reviews the types of information that can be inferred for measurement, description, and quantification of pore structures in rocks and other porous materials, including porosity, pore connectivity, surface area, surface roughness, pore size distribution, lacunarity, and other aspects of texture. Conventional petrophysical methods are put in context with the cutting edge of imaging methods (SEM, FIB-SEM, NMR, AFM) and scanning methods using X-rays or neutrons (SAXS, SANS). This chapter, together with the Noiriel chapter, which discusses X-ray microtomography (XMT), constitute a single "go-to" guide for anyone in the study of porous media characterization.

This volume presents a formalism for the relatively recent discoveries of the pore-size dependence of kinetics of geochemical reactions. Pore-scale processes are unique; they are not just smaller versions of the same processes that occur in the bulk or continuum scale. Confined spaces alter reactions because of the curvature of surfaces, the ordered structure of water, and the profound alteration of surfaces and solutions as reactions proceed. Putnis presents the evidence of and possible mechanistic explanations for why pore structure exerts a very significant influence on crystal growth. Recognition of the pore-scale is important to the field of geochemistry because, according to Stack, "nanopores may contain the largest deviations from bulk-like reactivity, and at the same, may constitute the majority of pores in a rock" (p. 186).



Another important contribution of this volume is the discussion of the interdependence of reaction and transport in porous media. Transport drives geochemical reactions because it causes advection of solutes, which results in chemical disequilibrium. Subsequent mineral dissolution and precipitation reactions produce volume changes that alter permeability. This in turn affects fluid flow and solute transport. The complicated feedback that arises could not be predicted without describing heterogeneities at the pore scale. Several of the chapters in this volume make important contributions to the understanding of the interplay between geochemical reactions and the evolution of porosity and pore structure, including the chapters by Putnis, Emmanuel et al., Noiriel, Røyne and Jamtveit, and Navarre-Sitchler et al. Discussions in these chapters highlight the importance of fluid-induced fracturing and its role in connecting porosity, which thereby perpetuate reactions. The chapter by Liu et al. focuses on the unique insights that are gained by experiments using 2D

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micromodel flow cells, which allow real-time observation of pore-scale reactions and inferences about reaction-induced pore structure and permeability changes.

Advancements in reactive transport modeling are now increasingly paired with the advancements in materials characterization. The chapter by Steefel et al. describes how micro-continuum models of porous media can be parameterized from the detailed characterization of pore structure, mineral mapping, and surface area. Additional chapters review models of fluid flow and reactive transport, including Lattice-Boltzmann approaches by Yoon et al., pore-network modeling by Mehmani and Balhoff, and direct numerical simulation of pore-scale processes by Molins. These models demonstrate the need to account for gradients at a range of spatial scales including those that drive diffusion through clay materials, as discussed by Tournassat and Steefel, and those that exist at the fluid-solid boundary, as discussed by Druhan et al.

In addition to being a review, this volume is also forward-looking. It is as relevant for leading researchers as it is for graduate students just beginning their studies. Some of the chapters talk about a future when we will be able to purposefully create desired chemical and hydrologic perturbations in porous media to control precipitation, and thereby control flow. Such engineered mineral reactions would find valuable application in multiple areas of scientific, environmental and industrial interest, including mineral/rock weathering, groundwater remediation, nuclear waste disposal, and geologic carbon sequestration.

Our insatiable desire to discover the secrets of molecules in small spaces, and even control their behavior, will motivate research on pore-scale geochemical processes for years to come, and this volume is both a map of recent advances and a guide to fruitful future research.

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Erratum: Book Review by Michael W. Foerster in vol. 101, p. 2361–2362 (2016).

Should read: Chapter 7 examines the significance of magnetic fabric ... mainly influenced by ferromagnetic minerals like Fe-silicates.